Technical Report 810

Changes in Knowledge Representation With Increasing Expertise

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Technologies for Skill Acquisition and Retention

Training Research Laboratory

U.S. Army
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Today's Army is highly dependent upon computer technology. Computers with specially designed applications software or "command languages" are integral to recruiting and record keeping, education and training, and maintenance and use of complex weapon systems. Since command languages are used in a wide variety of Army jobs, most soldiers will require training for at least one command language at some point in their Army career. The development of effective training for command language use depends upon an understanding of how this type of skill is acquired. This paper reports on research efforts to determine how the structure and use of knowledge for a command language changes as a function of increasing expertise with the language.

Lotus 1-2-3, a popular command language for spreadsheet construction, was chosen for investigation. Trainees first received a tutorial on Lotus 1-2-3. Their knowledge

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representations for Lotus commands and concepts were then mapped using the ordered tree technique (Reitman & Reuter, 1980), and their ability to use the language was assessed using spreadsheet construction and modification tasks. Afterwards, the trainees were required to use the command language to complete a relatively complex practical exercise. Their knowledge representations and ability to use the language were assessed a second time. (KR)

The results showed that there were qualitative changes in trainee knowledge of the software as command language skills were acquired. Specifically, trainee knowledge representations became more like those of an expert across the two testing sessions. This evolution in knowledge was accompanied by an increase in ability to accurately accomplish certain spreadsheet tasks.

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Education and Training

FOREWORD

A significant problem facing Army trainers today is the need to rapidly establish high levels of technological expertise in unskilled trainees. The development of programs to train soldiers with widely varying aptitude levels in these areas in a way that they can quickly comprehend and assimilate will depend upon the determination of how learning in these areas occurs. In response to this problem, research to investigate complex learning processes in computer technology was conducted by the Technologies for Skill Acquisition and Retention Technical Area (TSARTA). This task, titled "Use of ICAI in Training Systems," was organized under the "Train the Force" program area and was supported by the U.S. Army Engineer School (USAES). These research results were briefed to the Deputy Assistant Commandant, USAES in June 1986 and components were incorporated into the computer literacy training program for the Engineer Officers Advanced Course in October 1986.

EDGAR M. JOHNSON
Technical Director

CHANGES IN KNOWLEDGE REPRESENTATION WITH INCREASING EXPERTISE

EXECUTIVE SUMMARY

Requirement:

To investigate how trainee knowledge representations change as expertise in command language (Lotus 1-2-3) use is acquired and to determine whether these representations are related to ability to use the language.

Procedure:

Twenty-four MBA students at the University of Michigan who had no previous experience with Lotus 1-2-3 received a 1-1/2-hour tutorial on basic use of Lotus and were subsequently required to use the software in a class project. One week after the tutorial and at the end of the semester following completion of the class project, each trainee participated in a 2-hour data collection session that assessed their organization of Lotus knowledge and their ability to use the software.

Findings:

Comparisons of trainee knowledge representations obtained at the two points in the training period indicated how knowledge changed as trainees became more skilled in using Lotus 1-2-3; comparisons of trainee representations with the representation for an expert Lotus user indicated how novice trainee knowledge differed from expert knowledge. Over the training period trainee knowledge representations began to resemble expert representation; trainees with higher similarity to the expert demonstrated a better ability to use the software than those with lower similarity to the expert.

Utilization of Findings:

This research demonstrates that novice knowledge representations for computer command language skills change as these skills are acquired and also shows how novice representations differ from expert representations. This information has been used to develop a handbook and tutorial for Lotus 1-2-3 that will be placed in the U.S. Army Engineer School computer laboratory (The Army Engineer's Lotus 1-2-3 Tutorial and Handbook). This handbook and tutorial is unique because it contains instructional material designed to address student misconceptions and errors that were revealed by the present research. This research also shows that a method for mapping trainee and expert cognitive representations, the ordered tree technique, may be a candidate for incorporation into an ICAI system to aid in student modeling.

CHANGES IN KNOWLEDGE REPRESENTATION WITH INCREASING EXPERTISE

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CHANGES IN KNOWLEDGE REPRESENTATION WITH INCREASING EXPERTISE

INTRODUCTION

Assessing the cognitive state of the student is a fundamental aspect of all educational systems. Historically, however, this task has not been especially cognitive and has rested primarily on performance measures such as test scores, number of problems solved, speed of performance, etc. According to Ohlsson (1986), this performance-based approach assumes that knowledge of how much a student knows is more important than what that student knows. However, while this approach is distinctly non-cognitive in theory, in practice, creative teachers combine the information gained from these qualitative performance measures with an understanding of the subject matter domain and student learning characteristics to infer the cognitive state of their students.

In recognition of this fact, researchers in intelligent computer-aided instruction (ICAI) and in cognitive and educational psychology have begun to explore sophisticated methods that allow inferences to be made about cognitive structures and processes. Within the area of intelligent computer-aided instruction, methods have been developed that produce what is known as the "student model." These include the overlay method (Carr & Goldstein, 1977), the mal-rule and perturbation method (Brown & Burton, 1978), and various simulation methods (Ohlsson, 1986). In the overlay method, performance measures are used to determine mastery of specific knowledge elements contained in an internal representation of a subject matter domain. These elements are marked as proficiency increases so that student knowledge is modeled as an "overlay" on an expert representation of the domain. In the mal-rule method, the pattern of the correct and incorrect answers is matched against a library of errors or "bugs" and is used to infer student misconceptions that lead to deviations from proscribed procedures. In simulation methods, the cognitive steps taken to reach a particular problem solution are modeled and are then executed to determine whether they reproduce a student's solution (for a more extensive description of student modelling in ICAI, see Ohlsson, 1986).

Other methods for inferring cognitive state that are often used in the areas of educational and cognitive psychology include multidimensional scaling (Kruskal, 1964) and hierarchical clustering (Johnson, 1967). These methods are based on an analysis of distance measures between pairs of items. This information can be obtained from a variety of tasks such as similarity judgements, verification reaction times, number of items intervening between two recalled items, etc. Multidimensional scaling places items in an N-dimensional space in such a way that pair-wise distances are preserved. Hierarchical clustering produces a tree structure with nested clusters representing the distance between items. The output from these analyses can then be examined for the presence of cognitive structure that is consistent with the organization of concepts inherent in a particular domain. Although the methods for inferring cognitive state in intelligent tutoring systems differ somewhat from those used in cognitive and educational psychology, they are similar in that they focus on qualitative aspects of knowledge (e.g. what the knowledge is, how it is organized, and how it is used) rather than on quantitative aspects of knowledge. Moreover, they are all guided by the assumption that performance can be understood best in the context of the current state of the underlying cognitive structures and processes that mediate this performance.

The present research focuses on a novel method of inferring cognitive structure called the "ordered tree technique." This technique was introduced by Reitman & Rueter, (1980) as a means to recover consistent ordering of to-be-remembered items (TBR) in a mutitrial cued and non-cued recall task; it has since been extended to an item organization task (c.f. Navah-Benjamin, McKeachie, Lin, & Tucker, 1986). A basic assumption underlying this technique is that consistent ordering of items is a manifestation of the organization of the cognitive structures representing those items and of the cognitive processes operating on these structures. Specifically, items in memory are organized into chunks, and all items from one chunk are produced before items from another chunk. Chunks are further organized into a hierarchical tree with higher level nodes in the tree representing a mental code for a complete chunk. For example, a chunk consisting of the items "shoe," "glove," and "sweater" might be represented by the higher level node "articles of clothing." The ordering of items during production is a function of this hierarchical cognitive structure and of the traversal rules for the structure. These traversal rules may specify unidirectional access to items within a chunk (items are always produced in one order), bidirectional access (items are produced in one order or its reverse), or nondirectional access (items are produced in any order).

Using the ordered tree technique, it is possible to recover experimenter-imposed organizations for items as well as interpretable subjective organizations. Further, chunk boundaries in the ordered tree correspond well to pauses in recall (Reitman & Rueter, 1980). Recent studies have shown that the technique can differentiate between individuals with different skill levels in a particular domain (McKeithen, Reitman, Rueter, & Hirtle, 1981) and can show changes in cognitive organization for the same individual as learning occurs (Navah-Benjamin, et al., 1986). For example, McKeithen, et al. (1981) showed that novice programmers' ordered trees for reserved words in ALGOL were very different from intermediate and expert programmers' trees. Novice trees contained evidence of chunking by simple rules such as orthography (word length), first letter (alphabet), and story construction, whereas intermediate and expert trees contained chunks that were relevant only in the ALGOL context. In addition, experts' trees were more similar to each other than were novices' trees suggesting that experts were using similar cognitive representations to organize items. In another study using the ordered tree technique, Navah-Benjamin, et al. (1986) showed that students' trees for developmental psychology concepts became more organized and more similar to the instructor's tree over the course of a semester. Moreover, the degree of organization and similarity attained by the students at the end of the course were correlated with their final grades.

In the present study, we used the ordered tree technique to assess changes in cognitive structure for a high level computer command language as expertise in using that language was aquired. Computer command languages consist of a set of procedures that individuals can use to perform specific tasks. These languages employ a command-execute cycle (Moran, 1981) that differs somewhat from the program-run-execute cycle of traditional programming languages. Thus, use of these languages does not require programming skill (although many offer advanced features for more knowledgeable individuals). Some common examples of command languages are those used for text-editing, spreadsheet construction and manipulation, and data base design and manipulation. In addition, command languages are used in all military computer systems capable of performing a set of tasks in a manner that is under the control of an operator.

Lotus 1-2-3, a menu-based command language for creating and manipulating spreadsheets, was used as the task domain. Lotus allows a user to create a spreadsheet by inputing data into a two-dimentional grid space displayed on a computer screen (see Figure 1) and to manipulate this data using a variety of commands and functions (see Figure 2). One goal of this research was to gain some understanding of how skill in using this language is acquired and what software design features facilitate or hinder this process. This information will be important in developing better training for command language use in military settings. A second goal, and the one that is the focus of this paper, was to determine whether the ordered tree technique can illuminate changes in cognitive structure during the acquisition of procedural computer skills.

METHOD

Twenty-four MBA students at the University of Michigan who had no previous experience with Lotus 1-2-3 received a 1 1/2 hour tutorial on basic use of Lotus and were subsequently required to use the software in a class project. The tutorial consisted of a lecture and a spreadsheet construction practical exercise using a Burroughs personal computer system. The class project consisted of construction of a relatively complex financial spreadsheet. The students were allowed to work in groups for this project. One week after the tutorial and at the end of the semester following the completion of the class project, each student participated in a 2 hour data collection session in which their organization of Lotus knowledge was assessed. Data was collected at the same time for an expert who was using the Lotus 1-2-3 macro facility to develop decision aids.

The ordered tree technique was used to determine the organization of Lotus knowledge. Subjects were given a set of cards containing 32 words selected to represent a subset of procedural steps and related concepts in Lotus. They were asked to use their knowledge of Lotus to organize the words so that terms that were closely related in Lotus were close together in their organization. They listed this organization sequentially in a test booklet, shuffled the cards, and repeated the procedure 9 additional times. The test booklet contained 10 pages with 32 blank lines for the 32 Lotus terms. Eight of the 10 pages began with a different word from the subset of Lotus terms, and two pages began with an empty line. Subjects were

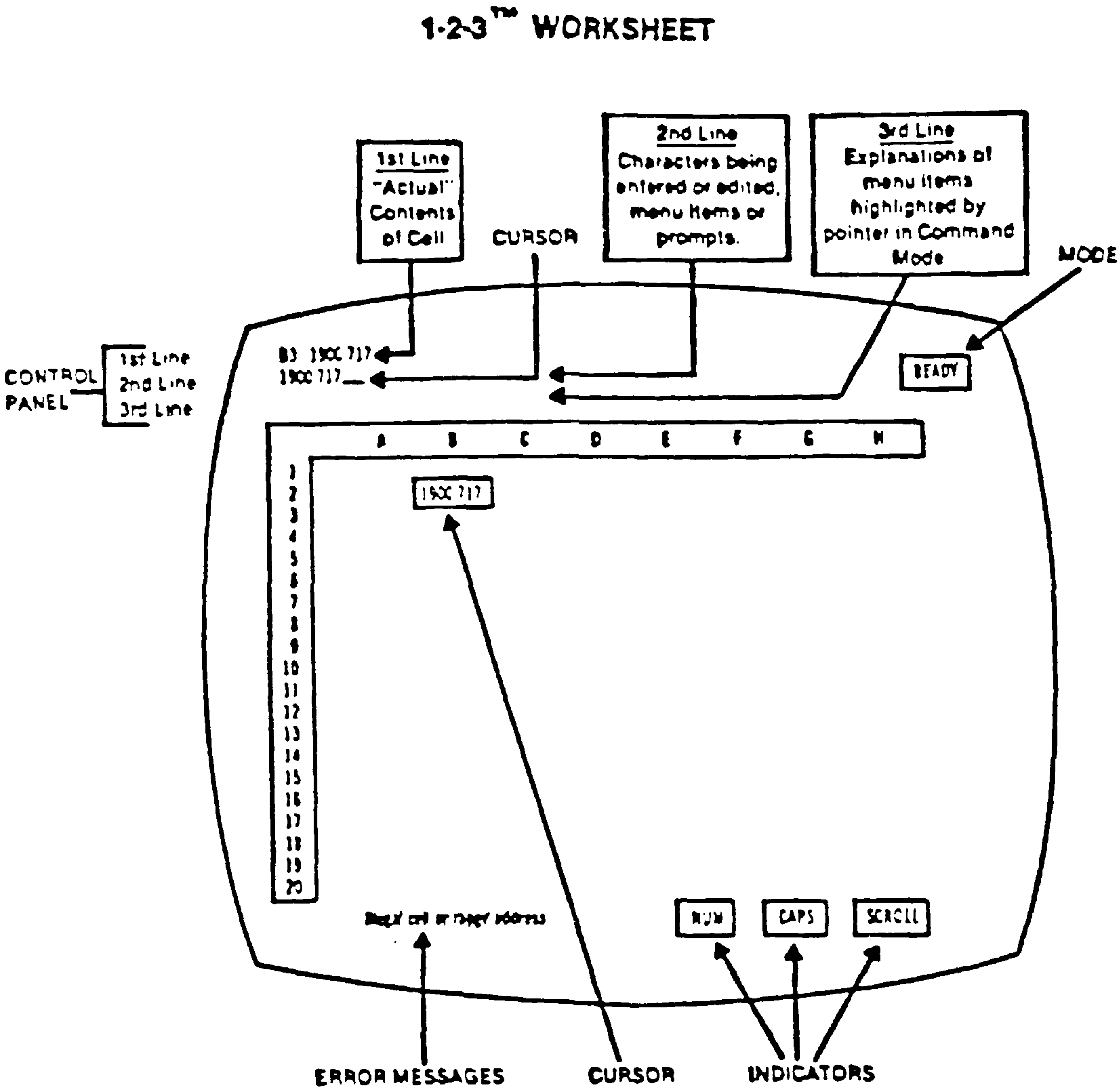

Figure 1. The Lotus 1-2-3 Screen

LOTUS® 1-2-3™ COMMAND STRUCTURE CHART

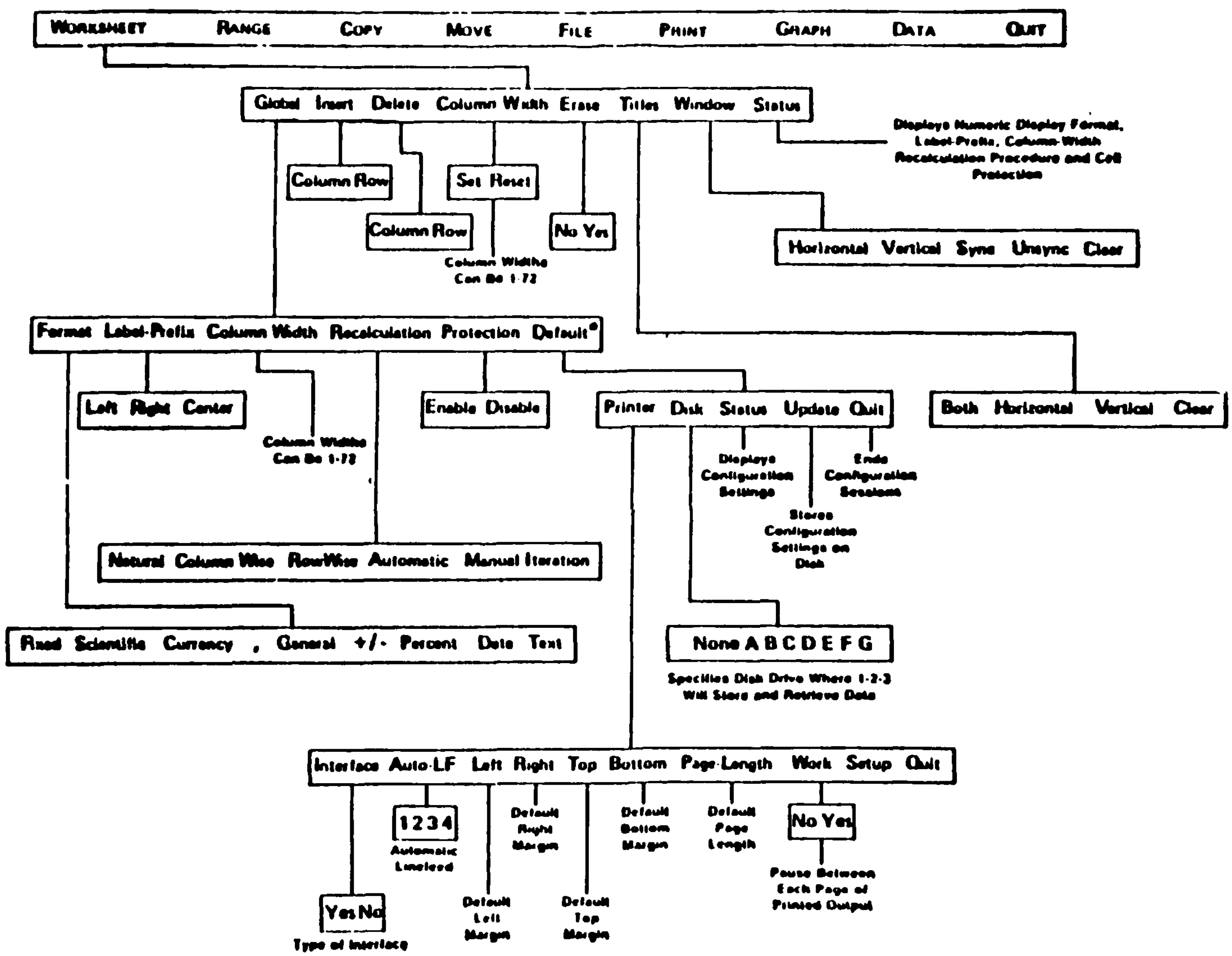

Figure 2. The Lotus 1-2-3 Command Structure Chart.

told that if a page began with a prespecified item, they were to begin listing their organization with words that were related to this word; if the first line was blank they were told that they could begin with any word they chose. This procedure yielded 10 orderings of the Lotus terms, which were then submitted to the ordered tree algorithm to determine consistent orderings of words within the data. This algorithm also produced a measure, PRO, of the degree of organization within a given tree structure. The lower this measure, the higher the organization in a tree.

Ability to use the Lotus software was assessed using two tasks. In a spreadsheet construction task, subjects received a spreadsheet printout and specifications and were asked to construct the spreadsheet themselves as accurately as possible. Following the construction task, they were asked to modify the spreadsheet they had constructed using several specific procedures. Different spreadsheets were used for each of the two sessions. However, these spreadsheets were constructed using the same template so that they were visually similar and required the same procedures to complete (see Figure 3). During performance of the spreadsheet construction and modification tasks, keystroke sequences and times were recorded yielding a sequentially ordered protocol for the procedures attempted and successfully or unsuccessfully completed. Four procedures were selected for analysis: widening column widths, inserting rows and columns, and constructing formulas and functions. The first two procedures required use of the LOTUS menu, the latter two did not.

RESULTS

Ordered trees for the expert and two typical novices are presented in Figures 4-6. Chunk boundaries or nodes are indicated by small circles, and chunk directionality is indicated by the arrow over the branches of a node. The absence of an arrow indicates a non-directional chunk.

It is clear from Figure 4 that there is a great amount of organization in the expert's ordered trees for Sessions 1 and 2 (PRO's = 24 and 25, respectively, out of a maximum of 117). Further, although the trees are not identical, the chunks they contain overlap considerably. The degree of overlap or similarity can be determined by computing the number of non-trivial chunks the two trees have in common (McKeithen, et al., 1981). This is given by the equation:

$$\ln(\text{intersection of trees} + 1)/\ln(\text{union of trees} + 1)$$

This equation produces a similarity value of .73 for the two expert trees out of a maximum score of 1.00. Thus, the expert seems to have used a similar cognitive representation to organize the Lotus terms in Sessions 1 and 2.

The expert's trees for both sessions reveal organization that is highly meaningful in the Lotus context. More importantly, the chunks represent both related concepts and frequent procedural sequences in Lotus. For example, the chunks LABEL - PREFIX - " - and MENU - VALUE - POINT represent concepts that are associated in Lotus but have no relationship outside of this command language. The chunks DELETE - INSERT - ROW - COLUMN - WIDTH and COPY - MOVE - FROM - TO represent procedural sequences. Interestingly, the normative directional association between TO - FROM has been reordered to correspond to the correct Lotus procedural sequence FROM - TO. Finally, in the Session 2 ordered tree, a high level unidirectional chunk representing the Lotus menu structure appears. The directionality of this chunk is congruent with what would be observed if one moved sequentially through each top level menu commmand and its sub-menu commands (See Figure 2 for a graphic representation of the LOTUS menu structure).

The ordered trees in Figure 5 were produced by a novice whose similarity to the expert increased substantially over the two sessions (.00 to .59). In the first session, the novice tree is poorly organized (PRO = 109) and bears no similarity to the expert tree. In session 2, however, greater organization has emerged (PRO = 42) and this organization begins to resemble that of the expert. For example, the terms INSERT - DELETE have been added to the original chunk and the new chunk begins to resemble the expert chunk. In addition, the novice has apparently gained a rudimentary representation of the menu structure as shown by the chunk / - MENU - WORKSHEET - RANGE - MOVE - COPY. Unlike the expert's representation of the menu, however, the novice's representation contains only top level menu commands. The Session 2 tree also shows that the novice has some misconceptions about Lotus. The symbol @ is used to indicate a FUNCTION in Lotus, but the novice has placed it with LABEL - PREFIX. LABEL - PREFIX should only be associated with the symbols ∨ and ". Thus, this novice apparently does not have a clear representation for the LABEL - PREFIX concept. In general, this novice's emerging representation can be characterized as relatively accurate but incomplete at this stage in learning. The ordered trees for the second novice (see Figure 6) also demonstrate an increase in organization (PRO = 117 to 109) and similarity to the expert (.00 to .31), but these increases are minimal. Further, the chunks present in this novice's Session 2 tree could be constructed using prior associations as well as Lotus knowledge.

These tree structures for an expert and two typical novices with differing levels of similarity to the expert show that the ordered tree technique can recover differences in cognitive representations for individuals with different skill levels and for the same individual after some learning of the skill has occured. In general, the expert showed greater organization than the group of novices in both Session 1 (PRO - 24 vs 70) and Session 2 (PRO - 25 vs 54) although organization did increase for the novices between the two sessions (PRO - 70 vs 54). To determine whether this increase in organization reflected relationships that were relevant to Lotus, the novice similarity scores for Sessions 1 and 2 were analyzed. These means were .26 and .36, respectively, and this increase in similarity was significant, $\underline{F}(1,23) = 6.92$, $\underline{MSe} = .017$, $\underline{p} < .01$. Thus, the novices' organization of Lotus terms increased over sessions and this organization also became more like that of an expert. This suggests that

Representative Spreadsheet Task

XYZ COMPANY
COMPARATIVE BALANCE SHEET

	December 31, 1984	December 31, 1983	Increase or Decrease
			DIFFERENCE
Current Assets:			
Cash	5500	4200	1300
Marketable Securities	1500	2400	-900
Accounts Receivable: Trade	61600	52000	9600
Accounts Receivable: Other	1417	1732	-315
Inventories	76000	63000	13000
Prepaid Expenses	900	600	300
Other Current Assets	2089	1600	489
SUM			
Total Current Assets	149006	125532	23474
Long Term Assets:			
Property, Plant & Equipment	4500	40000	5000
Investments	1800	1600	200
SUM			
Long Term Assets	46800	41600	5200
TOTAL ASSETS	195806	167132	28674
	SUM		

Figure 3. Representative spreadsheet task.

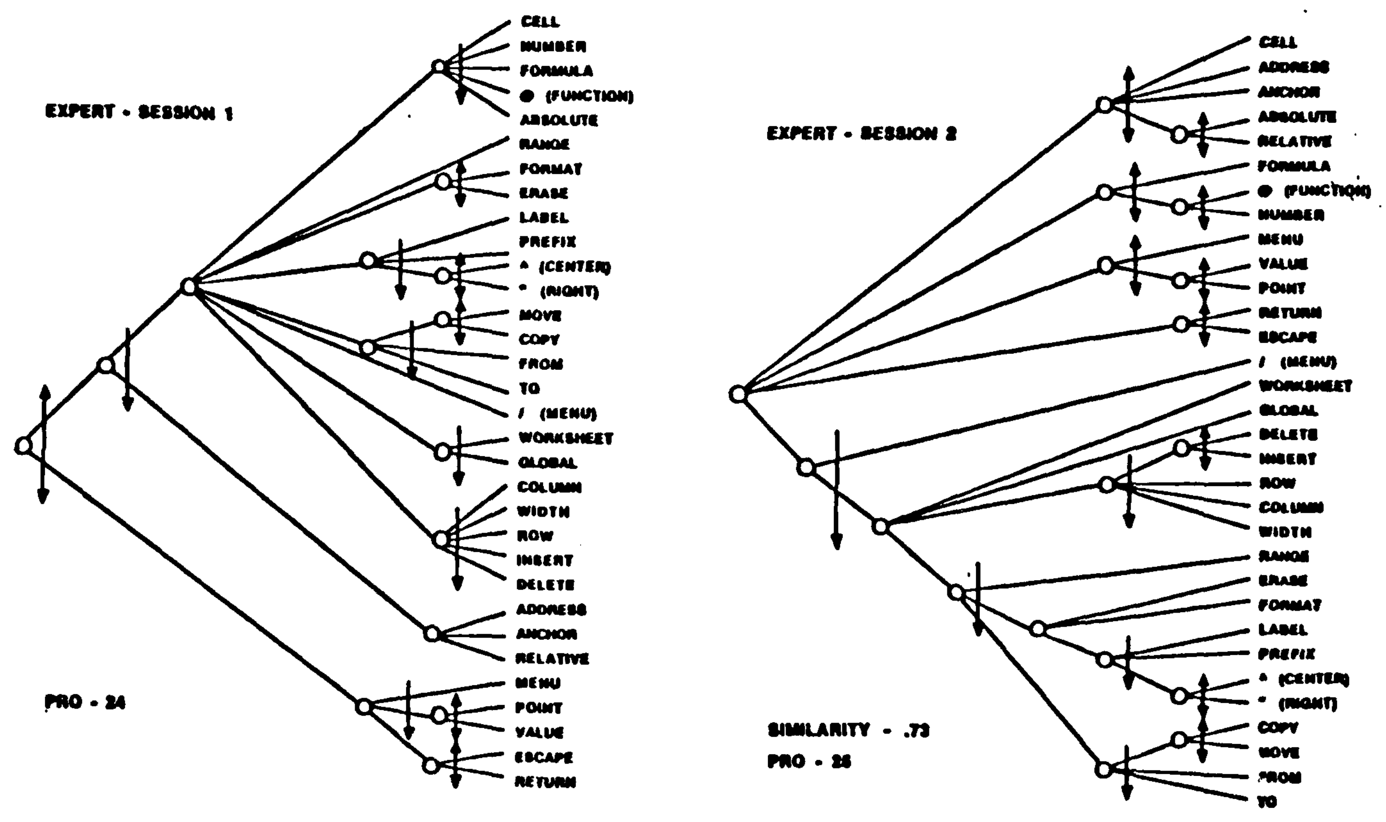

Figure 4. Expert ordered trees for sessions 1 & 2

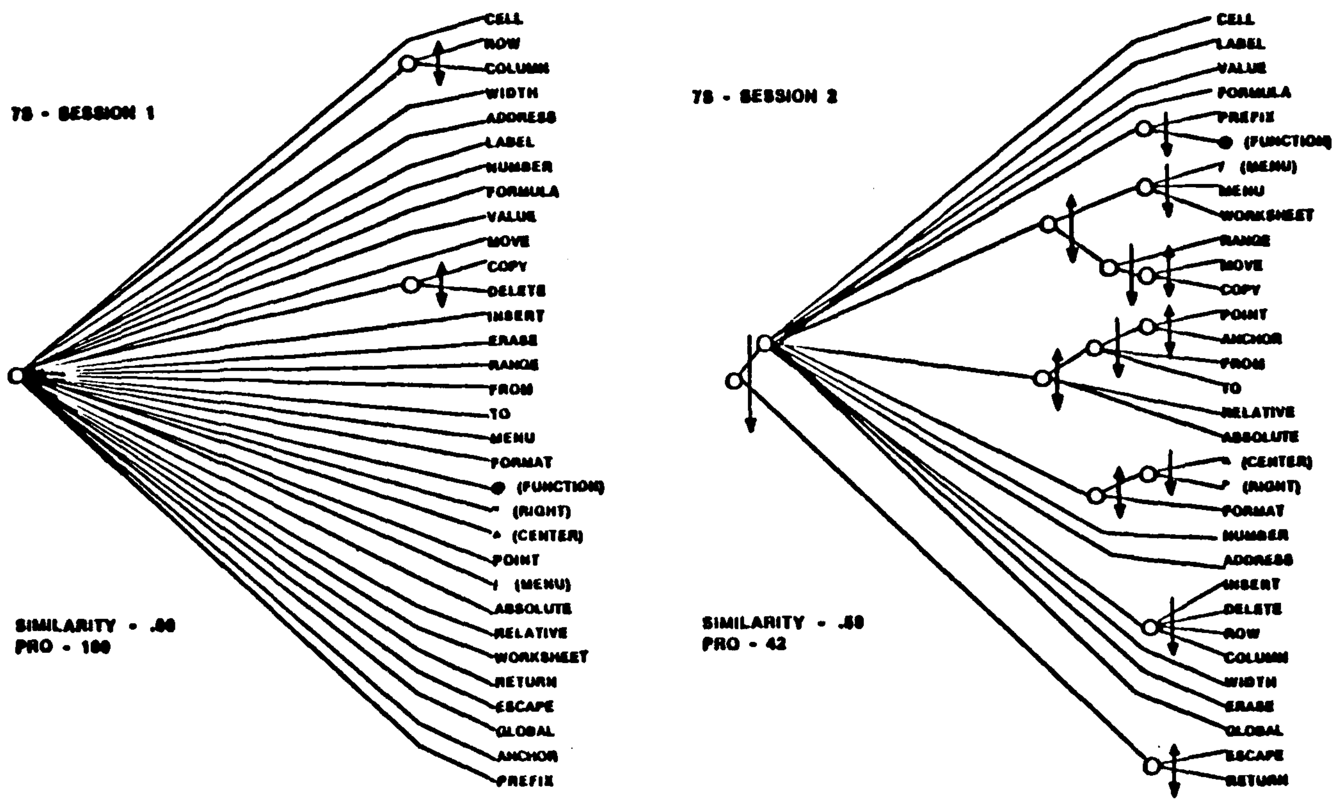

Figure 5. Novice ordered trees for sessions 1 & 2.
(Large increase in similarity to expert).

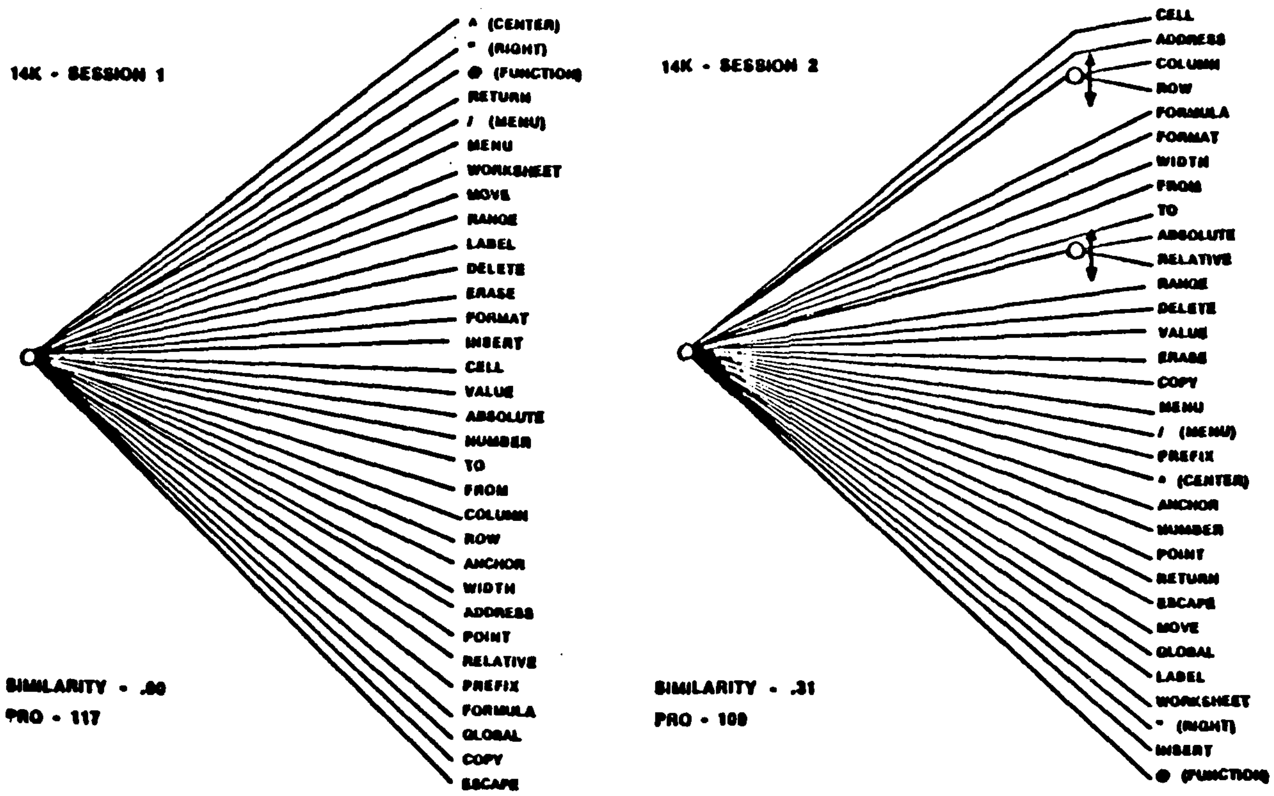

Figure 6. Novice ordered trees for sessions 1 & 2. (Small increase in similarity to expert).

the novices were beginning to develop an underlying cognitive representation for these items that reflected procedural sequences and related concepts in Lotus.

Two additional analyses were conducted to determine whether there was a relationship between the ordered trees obtained for novices and their ability to use the Lotus software. Error rates for the four procedures mentioned previously were used as the measure of ability. For the first analysis, the subjects were divided into subgroups on the basis of whether their similarity scores were higher or lower than the overall group median for Sessions 1 and 2. Subjects in the LOW group had similarity scores lower than the median in both sessions (N=7); subjects in the IMPROVE group had scores lower than the median in Session 1, but higher than the median in Session 2 (N=5); subjects in the REGRESS group had scores higher in the first session, but lower in the second session (N=6); and subjects in the HIGH group had similarity scores higher than the median in both sessions (N=6). The mean number of errors for these groups for the four procedures are presented in Table 1. A 4 (Group) X 2 (Session) X 4 (Procedure) ANOVA for this data revealed main effects of group, $F(3,30) = 6.91$, $MSe = .133$, $p < .022$, and procedure, $F(3,60) = 10.32$, $MSe = .137$, $p < .001$. No other main or interaction effects were significant. These results show that the HIGH similarity group made substantially fewer errors than the LOW, IMPROVE, and REGRESS groups, but that there was little difference between these latter three groups. Further, the overall increase in similarity between Sessions 1 and 2 does not appear to be matched by a corresponding decrease in the number of errors made, nor is there an interaction that would suggest that errors decreased for some groups but not for others. Thus, although the ordered trees show some correspondence to performance, this correspondance is not perfect.

Table 1
Mean proportion of errors by group, session, and task.

		Group				
Session	Procedure	Low	Improve	Regress	High	Mean
1	COL WIDTH	.30	.21	.17	.07	.19
	INSERT	.51	.36	.25	.14	.32
	FORMULA	.56	.41	.59	.33	.48
	FUNCTION	.53	.80	.68	.33	.57
	Mean	.47	.44	.42	.22	
2	COL WIDTH	.38	.07	.32	.09	.23
	INSERT	.32	.50	.32	.03	.29
	FORMULA	.79	.52	.40	.17	.48
	FUNCTION	.58	.63	.80	.36	.59
	Mean	.52	.43	.46	.16	

To obtain additional information about the relationship between the ordered trees and performance, correlations between similarity and error rates were obtained. These correlations are presented in Table 2. As the table shows, the only significant correlation between similarity and error rate in Session 1 was for the INSERT procedure. For Session 2, however, there were significant correlations between these factors for the procedures, widen column width, construct formula, and construct function. This suggests that after some skill has been acquired, similarity to the expert may be related to ability to use the software. This finding parallels previous findings that similarity is correlated with final course grades but not with grades in the beginning of a course (Navah-Benjamin, et al., 1986).

These results are consistent with earlier studies (McKeithen, et al., 1981; Navah-Benjamin, 1986) in showing that the ordered tree technique can reveal differences in cognitive structure for individuals with differing procedural skill levels and for the same individual as skill increases. There appears to be a relationship between the cognitive representation described by these ordered trees and procedural ability, especially for Session 2. However, this relationship is by no means as clear as desired. There are a number of possible reasons for this finding. Perhaps the Lotus terms chosen were not representative of the knowledge used for the procedures analyzed (i.e., performance was mediated by knowledge structures other than those represented in the ordered trees) or perhaps the measures of skill and ability to use Lotus were inflated because subjects could use contextual cues present in the software interface (e.g. the menu structure) to guide performance. These cues were not present during performance of the organization task. Alternately, it may be the case that a well-formed cognitive representation is not necessary for some minimal ability to use the software to be demonstrated.

Table 2
Correlations between similarity and error rate for each procedure.

Session	Procedure	Correlation
1	COL WIDTH	-.11
	INSERT	-.46 **
	FORMULA	-.07
	FUNCTION	-.05
2	COL WIDTH	-.47 **
	INSERT	-.02
	FORMULA	-.39 *
	FUNCTION	-.40 *

Despite the absence of a strong relationship between performance and the tree structures obtained in this experiment, the ordered tree technique appears to produce a valid representation of the underlying cognitive representations for Lotus. This technique has also been proven effective for inferring cognitive representations in a number of other domains, including programming in ALGOL (McKeithen, et al., 1981) and the psychology of aging (Navah-Benjamin, et al., 1986). Future applications for this technique may be its incorporation into an ICAI system to aid student modeling and its use as a "first-cut" method to elicit and organize expert knowledge during knowledge acquisition for expert systems.

REFERENCES

Brown, J. S., & Burton, R. R. (1978). Diagnostic models for procedural bugs in basic mathematical skills. Cognitive Science, 2, 155-192.

Carr, B., & Goldstein, I. (1977). Overlays: A theory of modelling for computer-aided instruction. MIT AI Memo 406.

Johnson, S. C. (1967). Hierarchical clustering schemes. Psychometrika, 32, 241-254.

Kruskal, J. B. (1964). Non-metric multidimensional scaling: A numerical method. Psychometrika, 29, 115-129.

McKeithen, K. B., Reitman, J. S., Rueter, H. H., & Hirtle, S. C. (1981). Knowledge organization and skill differences in computer programmers. Cognitive Psychology, 13, 307-325.

Moran, T. P. (1981). The command language grammar: A representation for the user interface of interactive computer systems. International Journal of Man-Machine Studies, 15, 3-50.

Naveh-Benjamin, M., McKeachie, W. J., Lin, Y., & Tucker, D. G. (1986). Inferring students' cognitive structures and their development using the "ordered tree technique." Journal of Educational Psychology, 78, 130-140.

Ohlsson, S. (1986). Some principles of intelligent tutoring. Instructional Science, 14, 293-326.

Reitman, J. S., & Rueter, H. H. (1980). Organization revealed by recall orders and confirmed by pauses. Cognitive Psychology, 12, 554-581.